The RS CVn Binary HD 155555: A Comparative Study of The Atmospheres For The Two Component Stars

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Abstract. We present GHRS/HST observations of the RS CVn binary system HD 155555 (see Dempsey et al., these proceedings). Several key UV emission lines (Fe XXI, Si IV, O V, C IV) have been analyzed to provide information about the heating rate throughout the atmosphere from the chromosphere to the corona. We show that both the G and K components reveal features of a chromosphere, transition region and corona. The emission measure distribution as a function of temperature for both components is derived and compared with the RS CVn system, HR 1099, and the Sun. The transition region and coronal lines of both stars show nonthermal broadenings of $\sim$ 20-30 km s^{-1}. Possible physical implications for coronal heating mechanisms are discussed.

1. Introduction

RS CVn binary systems represent a rich physical laboratory of magnetic activity where one or both (giant/subgiant G-/K-type star and late-type star/subgiant component) stars show strong soft X-ray, UV and radio emission and flare activity (Swank et al. 1981; Dempsey et al. 1993; Morris & Mutel 1988). ROSAT data suggested that coronae of these stars typically indicate a bimodal plasma temperature's distribution consisting of a warm 1-2 MK and a hot component with T = 10-20 MK. Recently GHRS/HST and EUVE observations of HR 1099 binary system show a strong emission at 1354Å from the Fe XXI ion formed at 10 MK and no significant emisson at 10^6K. Moreover, the HR 1099 system shows broad chromospheric, transition region and coronal lines while the K component reveals itself in Fe XXI 1354Å emission line without any observable flux in chromospheric lines (Robinson et al. 1996; Wood et al. 1996). Robinson et al. (1996) have discussed the nature of atmospheric heating in terms of non-linear surface Alfvén waves depositing its energy mostly in the transition region and contributing to the non-thermal broadening of UV lines formed at T= 0.1 - -0.3 MK.

HD 155555 is a short period (P=1.8 d) RS CVn binary system recently observed by the GHRS/HST and EUVE during the multiwavelength campaign (Dempsey et al. 1997). Pasquini et al. (1991) presented some evidence that

HD 155555 is a system composed of two young pre-main sequence stars. The objectives of the present study are to study two components separately in order to understand their evolutionary status (young main sequence component versus evolved subgiant) and atmospheric heating mechanisms. These unique, high-resolution data allow us to measure volumetric emission measures for both the G5 IV and KOV-IV components over a wide range of temperatures. Since the data were taken simultaneosuly we can compare the two spectral types directly. Furthermore, we can compare the results to those found for the RS CVn V711 Tau (HR 1099). In this paper we analyze the GHRS data obtained around phase 0.4. The data should not be affected in any way by the flare occuring near phase 0.6, however, phase related effects, although small, may be present. The EUVE data represent the flux integrated over the *entire* 5 day interval. Resolution in EUVE data are not adequate to resolve both stellar components.

2. GHRS, EUVE and ROSAT data: Comparative Analysis

2.1. Volumetric Emission Measures

GHRS/HST spectra near phase 0.4 clearly show the presence of emission from chromospheric, transition region and coronal lines belonging to the K- and G components and presents an unique opportunity for comparative study. In the Table 1 we present emission line fluxes from a number of lines forming throughout the stellar atmosphere with the temperature range from 10^4 to 10^7 K.

Table 1.   Emission Line Fluxes in 10^{-14} erg cm^{-2} s^{-1}

Emission Line	HR 1099	G/HD 155555	K/HD 155555
Chromosphere			
OI 1304 Å	130.0	4.34	3.0
SiII 1817.56 Å	135.0	9.8	6.6
Transition Region	-		
HeII 1640 Å	155.1	123.3	97.4
SiIV 1393 Å	75.5	9.32	4.95
CIV 1550 Å	313.2	18.0	13.7
OV 1371 Å	1.9	0.61	0.59
Corona			
FeXXI 1354 Å	3.1	1.9	8.89

It is evident that the flux ratio of the optically thin OV 1371Å line to the Fe XXI 1354Å for HR 1099 and the G component of HD 155555 is 0.6 and 0.3 respectively, while for the K component this ratio is only 0.07. We also see that the Fe XXI 1354 Åline flux from the K component of HD 155555 has the dominant contribution (~ 82 %) to the total emission from the binary system.

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HD 155555 system has also been simultaneously observed by EUVE but the low spectral resolution does not allow us to resolve both components. Nevertheless, a comparative analysis of Fe XXI 1354Å emission in both components allows us to calculate the flux coming from the EUVE lines formed at T=10 MK from both components.

For an optically thin plasma the integrated flux, I_j, at the earth from a given emission line, j, can be estimated from the expression;

$$I_j = \frac{1}{4\pi d^2} \int_V P_j(N_e, T_e) \, N_e^2 \, dV \quad \text{erg cm}^{-2} \, \text{s}^{-1} \, \text{str}^{-1} \qquad (1)$$

where P_j is the integrated line emissivity (in erg cm^3 sec^{-1}) and d is the distance to the star, N_e and T_e are the electron density in cm^{-3} and temperature respectively. For an isothermal plasma this can be written in terms of the volumetric emission measure, VEM $= \int_V N_e^2 \, dV$, as:

$$I_\lambda = \frac{1}{4\pi d^2} P_\lambda(N_e, T_e) \, VEM, \qquad (2)$$

From the observed line fluxes presented in Table 1 and EUVE line fluxes for UV lines from Fe XIII - Fe XXIII ions (Demspey et al. 1998) we calculate volumetric emission measures. Because emission from Fe XII 1349 Åhas not been detected we calculate the upper limit of the VEM from this line. In these calculations we have used line emissivity values tabulated by Monsignori-Fossi & Landini (1996) and Brickhouse et al. (1995). The results are presented in Table 2. In

Table 2.   VEM from GHRS and EUVE fluxes: K/HD 155555

Ion	Wavelength	VEM	Log T
CIV	1550Å	51.4	4.8
OV	1371Å	51.3	5.4
FeXII	1349Å	<51.7	6.0
FeXVIII	93.93Å	52.7	6.8
FeXIX	108.37Å	52.6	6.9
FeXX+XXI	118.66Å	52.6	7.0
FeXXI	117.51Å	53.3	7.0
FeXXI	1354Å	53.5	7.0
FeXXIII+XX	117.5Å	52.7	7.2

Fig. 1. we present a distribution of VEM over temperature adding the VEM values at 2 MK and 12.3 MK of the K component calculated by Dempsey et al. (1993) from the two-temperature thermal model. Here the triangles represent the VEM values from the GHRS/EUVE emission line fluxes and squares are the fluxes from ROSAT data. The VEM at T = 10 MK is scaled with the factor of 0.82. Fig. 1 shows that the VEM distribution of the K component
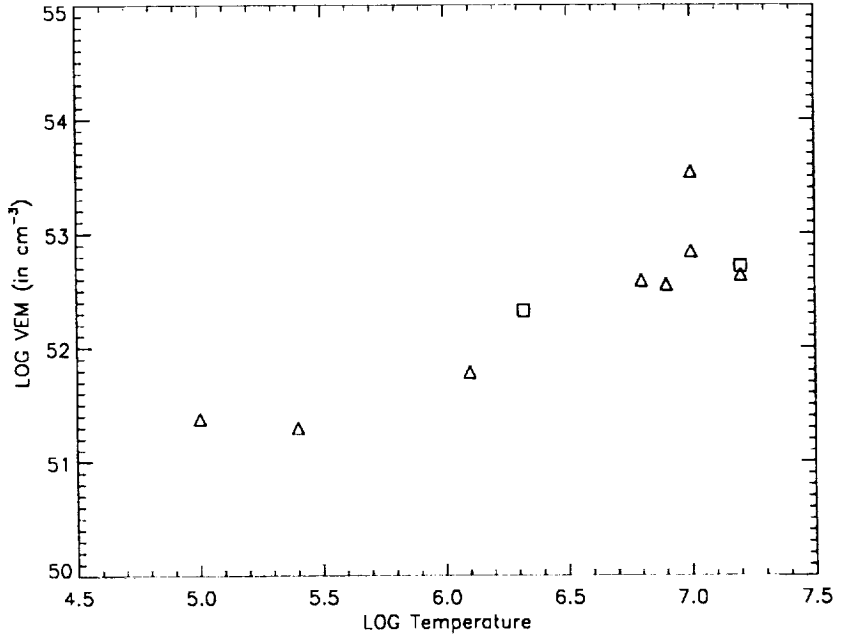
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Figure 1.   VEM distribution as a function of temperature for the K component of HD 155555

has a minimum at T =1 MK and a maximum at $\sim$ 10 MK which is typical for dMe stars, AT Mic and AU Mic (Monsignori Fossi et al. 1995, 1996). The VEMs derived from ROSAT data by Dempsey et al. (1993) are consistent with GHRS and EUVE data and, therefore, with the assumption of thermal nature of coronal plasma in the K therefore, with the assumption of the thermal nature of coronal plasma in therefore, with the assumption of thermal nature of coronal plasma in the K component. the K component.

Assuming for simplicity that the spherically symmetric corona is filled with semicircular magnetic loops (with a filling factor f) extending to radius R_*, all of which contains hot plasma, we have (Robinson et al. 1996)

$$VEM \sim N_e^2 V \sim f N_e^2 [\frac{4}{3}\pi(R^3 - R_*^3) - \pi R_*^2 (R - R_*)] \qquad (3)$$

From the scaling law for the homogeneously heated quasistatic magnetic loop

$$N_e L = 9.12 \times 10^8 \; T_e^{\frac{13}{12}}, \qquad (4)$$

and equation 3 we find that the upper limit for loop length (if f=1) is $L_{loop} \approx$ 10^9 cm and $N_e \approx 10^{11}$ cm^{-3}. Compact and high-density hot coronae were found also from EUVE data for dMe and RS CVn stars (Monsignori Fossi et al. 1996; Robinson et al. 1996).

The VEM distribution over temperature calculated for the G- component of HD 155555 and the active, K-component of HR 1099 is presented in Fig. 2.
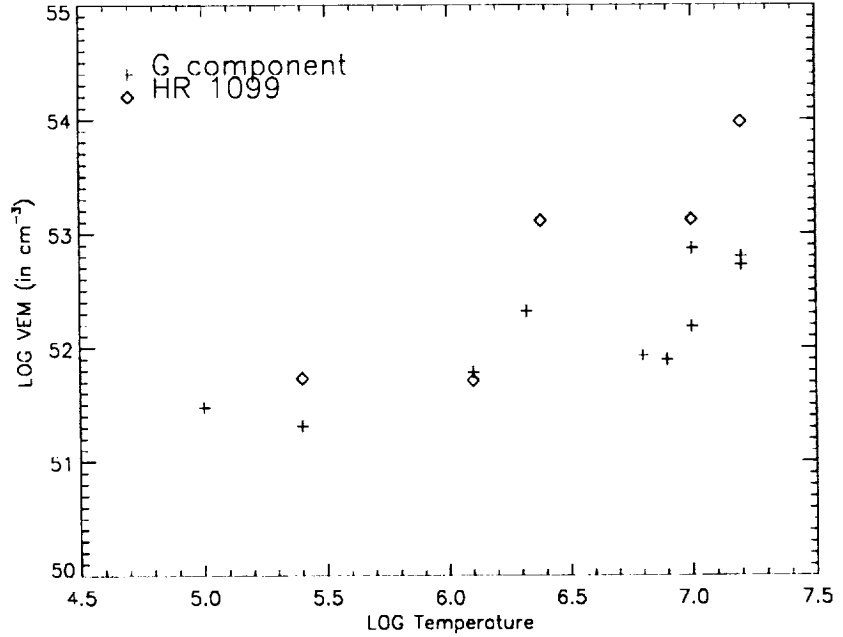
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Figure 2. VEM distribution for HR 1099 and G-components of HD 155555

We use GHRS, EUVE and ROSAT data for the G component of HD 155555 and GHRS and ROSAT data for HR 1099. VEM curves for both stars also show a minimum at T = 1 MK but do not show a pronounced maximum at 10 MK as for the K-component (see Fig 1) but have a monotonic growth of temperature for T > 1 MK. This is consistent with the VEM curves calculated for two other RS CVn systems, II Peg and λ And (Mitrou et al. 1996).

2.2. Non-thermal Widths

Recent GHRS observations of the RS CVn system, HR 1099, have shown the presence of supersonic turbulent motions in the chromosphere and transition region of the G star with velocities up to 150 km s^{-1} as traced by nonthermal broadening of UV lines fromed throughout the atmosphere. Their line profiles can be accurately reproduced using a superposition of two Gaussian profiles and have been explained by the presence of anisotropic macroturbulence (Robinson et al. 1996). However, optically thin UV lines in AU Mic have profiles which can be fitted by a single Gaussian profile and have substantially smaller turbulent velocities than those observed in HR 1099. Our analysis of the UV lines of both two components of HD 155555 also shows that they reveal non-thermal or turbulent broadening. The results of line width calculations are presented in Table 3.

An asterisk denotes a presence of the two-Gaussian profile.

As we have shown above, HR 1099 and G component of HD 155555 also show similarity in the relatively large contribution of transition region fluxes in

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Table 3. Turbulent velocities in HR 1099, G and K component of HD 155554

Emission Line	HR 1099	G	K	Log T
SiIV 1393Å	179.0*	42.7	34.7	4.8
HeII 1640Å	154.0*	159.0*	12.0	4.9
OV 1371Å	150.0*	≥ 39.3*	27.7	5.4
FeXXI 1354Å	65.0	35.3	20.0	7.0

OV 1371Å with respect to Fe XXI 1354Å and with the VEM distributions. These similarities can be understood in terms of one common mechanism of atmospheric heating. One possibility, heating due to dissipation of nonlinear surface Alfvén waves, has been described by Robinson et al. 1996.

Meantime, profiles of optically thin UV lines of the K component of HD 155555 are similar to the profiles of AU Mic and do not show strong nonthermal velocities or the presence of anisotropic turbulence. The ratio of OV (1371Å)/Fe XXI(1354Å) is much less than for the HR 1099 or G component. VEM distribution over temperature for the K component of HD 155555 is also similar to those observed in dMe star, AU Mic and in the solar atmsophere (Antonucci & Dodero 1995). These authors discussed such features in terms of heating due to microflares in the solar atmosphere.

3. Conclusion

Our comparative analysis of the K and G components of the RS CVn system, HD 155555, shows that

1. The G-component of HD 155555 shows a much larger ratio of OV 1371Å to Fe XXIÅ than the K component or either the active component in HR 1099.

2. The VEM distribution of the G-component of HD 155555 shows monotonic increase of the emission measure with temperature, while the VEM distribution for the K-component has a pronounced maximum at T=10 MK and is consistent with the curve characteristic of AT Mic and AU Mic.

3. The G-component of HD 155555 and the active component of HR1099 show features of significant anisotropically distributed macroturbulence, while the K-component of HD 155555 lacks these features similarly to the dMe stars, AT Mic and AU Mic and the Sun.

We suggest that the G-component of HD 155555 and the active component of HR 1099 have a common mechanism of atmospheric heating associated with dissipation of non-linear surface Alfvén waves in magnetic loops. However, the

K-component of HD15555, dMe stars and the Sun also show similar features of atmospheric heating and can be explained in terms of nano/microflares.

In conclusion, we note that the similarity of the K component of HD 155555 with dMe stars in a number of discussed features is consistent, in part, with the suggestion made by Pasquini et al. (1991) that HD 155555 is composed of two pre-main sequence star. At least, the K-component could be a young star with high-Li content. The G-component show features of a typical subgiant/giant RS CVn component.

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